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16. ABSTRACT: The report gives results of a study of the application of fabric filtration to combustion sources, with emphasis on research and development efforts directed toward assessment and documentation of full-scale baghouse operation, better understanding of the filtration process, and improvements in current technology. Performance tests show baghouses capable of very low particulate emissions (0.0035 lb/million Btu input), very high reliability (nearly 100%), and cost competitiveness with ESPs at high required efficiencies, low sulfur content coal, and/or small boiler size. Proper operation and maintenance are required, as with any high efficiency system. Fabric filtration is a comparatively recent method for controlling fly ash from combustion sources. A variety of fabrics, cleaning methods, and air/cloth ratios are being used, with utilities tending to use woven glass bags, reverse-air cleaning (sometimes with shake assist), and air/cloth ratios between 2 and 3. Industrial boiler users, in some cases, may use pulse-jet or modified reverse-air cleaning. Teflon, needled glass, Nomex, acrylic, or other fabrics, and air/cloth ratios up to about 9. Municipal incinerators are also effectively controlled by baghouses.

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Combustion	Stationary Sources	21B
Fly Ash	Fabric Filters	
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JOURNAL ARTICLE

APPLICATION OF FABRIC FILTRATION TO COMBUSTION SOURCES

J. H. Turner

Fabric filtration is a comparatively recent method for controlling fly ash from combustion sources. A variety of fabrics, cleaning methods, and air-to-cloth ratios is being used, with utilities tending to use woven glass bags, reverse-air cleaning (sometimes with shake assist) and air-to-cloth ratios between 2 and 3. Industrial boiler users, in some cases, may use pulse-jet or modified reverse-air cleaning, Teflon, needled glass, Nomex, acrylic, or other fabrics, and air-to-cloth ratios up to about 9. Municipal incinerators are also effectively controlled by baghouses.

Performance tests show baghouses capable of very low particulate emissions (0.0035 lb/10⁶ BTU input), very high reliability (nearly 100%), and cost competitiveness with ESP's at high required efficiencies, low sulfur content coal, and/or small boiler size. Proper operation and maintenance are required, as with any high efficiency system.

R&D efforts are directed toward assessment and documentation of full scale baghouse operation, better understanding of the filtration process, and improvements in current technology.

INTRODUCTION

Fabric filtration is one of the older forms of dust and particle control, but until recently it has not been used as a particulate control device for combustion sources. This paper will describe the application of fabric filters (baghouses) to three types of combustion sources; coal fired industrial boilers, coal fired utility boilers, and refuse fired boilers/municipal incinerators. Some specific examples will be given which include performance and cost justifications for choosing the baghouse.

Utility boilers (boilers greater than 250 million B.t.u.* input) have generally been equipped with electrostatic precipitators (ESP's) for particulate control. Until the New Source Performance Standards (NSPS) were promulgated in 1971 there was no uniform demand on ESP capability. ESP's operated at efficiencies between 70 and 99%. At the lower end of this efficiency range, ESP's were clearly more economical to use than baghouses particularly in view of the uncertainties associated with glass filter bags 10 years ago. The NSPS requirement of no more than 0.1 lb.** of particulate matter emitted per million B.t.u. input to the boiler has changed the situation. The equivalent efficiency requirement is on the order of 99.5%. As ESP's are designed for higher efficiency, their size and cost become larger. Traditional reverse air cleaned baghouses are inherently on the order of 99.9% efficient. As ESP's grow larger in efficiency, size, and cost, they begin to equal or exceed the total annualized cost of baghouses. The efficiency at which cost for the two devices is equal is different for different conditions and depends on such variables as fly ash characteristics, unit size, collection temperature, and geography.

EMISSIONS REGULATIONS AND GEOGRAPHY

Along with Federal standards, there are also State standards to be considered. States may set their own standards if they are not less stringent than the Federal standard. Several states have chosen to set more stringent standards. For example, New Mexico requires an emission limit (for utility boilers) of not more than 0.05 lb./10^6 B.t.u., of which not more than 0.02 lb. may be of material less than 2 μm in diameter. There is no Federal standard for industrial boilers

* 1 B.t.u. = 1055 joules

** 1 lb. = 454 grams

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(those of less than 250 10^6 B.t.u./hr. input). However, many states have already set an industrial boiler standard, often the same as for utility boilers. For municipal incinerators there is a Federal NSPS of 0.08 grains/d.s.c.f.;* but Massachusetts, for instance, has a municipal incinerator standard of 0.05 grains/d.s.c.f. States may also apply their standards to existing sources instead of just new sources, and definitions of new source may vary; e.g., revisions to an existing facility may or may not constitute a new source.

Geographical placement has effects in addition to differences in standards. Western coals tend to have lower sulfur content than eastern coals. This fact leads to higher resistivity fly ash which is harder to collect in an ESP. Western ESP's must then be sized larger than eastern ESP's; more specifically, ESP's for low sulfur coal are generally larger than ESP's for high sulfur coal when designed to the same collection efficiency.

Now consider the baghouse. Given the condition of high resistivity fly ash, the present requirement for high collection efficiency and the probable future requirement for even higher collection efficiency, the baghouse appears as an attractive alternative to the ESP. Western locations would be the obvious places to try baghouses on coal fired boilers. Why then was the first full scale baghouse on a utility boiler placed in service in the east. The answer lies in the resistivity of the fly ash: Pennsylvania's high resistivity anthracite silt fly ash does not lend itself well to electrostatic precipitation. Western Precipitation (Company) provided an eastern baghouse to take care of the situation. The Sunbury Power Station has become famous for the effective use of a baghouse on a utility boiler, and Pennsylvania Power & Light Company has had good enough experience so that they now have baghouses operating, on order, or under consideration for three more plants.

Where Are Baghouses Being Used?

The second full scale utility boiler application was at the Nucla Station of Colorado Ute Electric Association. The performance of both Sunbury and Nucla has been reported in detail (1,2,3). Both boilers are, however, atypical of what one would expect to find as a utility boiler. Sunbury burns anthracite silt, and Nucla uses stoker fired boilers. Nevertheless, their performance (and to some extent the performance at the oil fired Alamitos Station in California) has prompted a number of other users to order baghouses not only for utility boilers, but for industrial boilers as well. EPA published a list of baghouse installations on coal fired boilers in 1975 (4): 21 installations were either operating or on order. Now over 60 installations would be listed.

About half of the installations are on pulverized coal fired boilers. Most of the others are on some form of stoker fired boiler, and a few are on hog fuel boilers. About half the installations are west of the Mississippi (two of them are about as far west as you can get: Australia). Canada has at least one installation, and West Germany is building its first.

Unit size varies from about 1 to 1500 MWe., but most baghouses are on industrial boilers of less than about 50 MWe. One of these smaller units (Carborundum) has been in operation since 1967.

Why Are Baghouses Being Used?

Aside from the obvious condition that baghouses cost less than other devices for certain circumstances, there are many reasons why baghouses are attractive, or why the costs are less.

UTILITY BOILERS

The utility boiler design, based on carbon black manufacture, calls for use of woven glass fiber bags operating at an air-to-cloth ratio (filtering velocity) of about 2:1 (2 ft./min.*), and being cleaned by a gentle, reverse-air method. (Note that carbon black industry baghouses are used to collect a valuable product. The baghouses are part of the money-making process and are treated as such. They receive good maintenance and attention to detail.)

For utility usage, the major requirements are that the devices maintain proper emission levels and operate reliably. The Sunbury and Nucla reports indicate no problems in meeting emission standards. Nucla, for

*1 grain/d.s.c.f. = 2.288 grams/d.m.^{3}

*1 ft./min. = 0.508 cm./sec.

instance, had an overall mass emission of 0.0035 lb./10^6 B.t.u. (0.001 gr./s.c.f.), and an opacity at the stack of 0.02 to 0.6%. At the time the most recent report (3) was written, baghouse availability was 100% and compartment availability 99.8%; i.e., 0.2% of the time one or more compartments were out of service for maintenance.

Comparisons with ESP's are inevitable since they have been the principal particulate control devices for utility boilers for over 40 years. The importance of fuel sulfur content has already been mentioned: for low sulfur coal there is a cost incentive to go to baghouses above a certain required efficiency. Another factor is size: ESP's tend to become more expensive (per unit of gas treated) as they become smaller at a faster rate than baghouses.

Because large baghouses have many compartments, a single compartment can be taken out of service for maintenance whenever required without having much effect on overall baghouse operation or performance. Broken bags can be replaced at any time. Baghouses are also not particularly load-or fuel-sensitive. Large swings in gas load tend to be damped out by the baghouse. Fuel sulfur content is not a consideration from a performance standpoint, a characteristic that has influenced the selection of at least one set of baghouses (5).

Reasons for preferring an ESP over a baghouse include familiarity, pressure drop, and fabric related problems. The 40-plus years of experience with ESP's on utility boilers is not to be lightly regarded. Although much more than 40 years of experience exists with baghouses, that experience is not in the utility industry. Those familiar with ESP's are used to seeing pressure drops of an inch* of water or less on older units. The Sunbury and Nucla pressure drops are on the order of 2.5 to 5 in. H_2O. This pressure loss, and corresponding energy cost, is significantly higher than that for the older typical ESP.

The heart of a fabric filter is the fabric. Bags can be torn, blinded, burned, and otherwise ruined in a variety of ways if subjected to stresses not designed for. If worried about the frailty of fabric, one may forget that it has great strength when used as designed. Consider that, if you were ever a passenger on a DC-3, your flight was influenced by cotton or polyester covered control surfaces subject to the abuses of scorching sunlight, violent rainstorms, and even pounding hail.

If the flue gases entering an ESP or baghouse are cooled below their acid dew point, there will be corrosion of the structure and its internal components. In a baghouse there is a further consideration: condensation may plug the fabric so that pressure drop increases even beyond the system fan capacity. The condition is often temporary and reversible, but may be irreversible (blinding) unless the bags are specially cleaned. In some cases the fabric may be so affected as to be useless, necessitating re-bagging the house. It is obvious that precautions and controls are required in the fabric filter system to avoid or control consequential dew point excursions.

Some additional information given by Hudson (5) about TVA calculations is that (for Shawnee Station) a baghouse operating at less than 4 in. H_2O pressure drop uses less energy than an ESP at 1 in. H_2O. TVA's overall economic evaluation shows the total capital and operating costs of a baghouse to be 76% of those of an ESP for an assumed 3-year bag life. The Sunbury bags lasted more than 4 years.

INDUSTRIAL BOILERS

The industrial boiler population is probably much more diverse than that of utility boilers. In some instances there is less space available for control equipment, and less money available for purchasing it. Industrial boiler owners in states requiring substantial control have shown less reluctance to go to baghouses with higher air-to-cloth ratios, more energetic cleaning methods, different bag materials, non-woven fabrics, or different configurations than seen in utility applications.

Baghouses were originally cleaned by shaking after halting the gas flow through the bags. With the advent of glass bags, the gentler reverse-air cleaning system was developed. A nearly parallel development was the pulse-jet cleaned baghouse using non-woven fabrics. In this type of baghouse the bag is supported by a cage and gas flow is from the outside in. Cleaning is by a short, sharp burst of compressed air, downward from the top of the bag. The pulse-jet baghouse is also different in that cleaning is performed on-line (the air burst effectively shuts off each bag being cleaned by momentarily reversing flow through it) and the air-to-cloth (A/C) ratio is

*1 inch = 2.54 cm.

ordinarily substantially higher than for reverse-air or shake-cleaned baghouses. It was not for some years that non-woven fabrics were perceived as allowing the higher A/C ratio. Some European practice has been to use non-woven fabrics in reverse-air or shake-cleaned units and at higher A/C ratios; but that practice did not take hold in the U.S. until a few years ago when introduced by McKenna (4). The advantage of the higher A/C ratio is in having a smaller, less costly structure. Depending on the characteristics of the dust and fabric, the pressure drop may or may not be higher than for the traditional A/C ratio, baghouse efficiency may or may not be less, and bag durability may or may not be better. Bag cost is generally higher, but total annualized cost not necessarily so. Since pulse-jet cleaning is much more vigorous than reverse-air, glass-fiber bags have not generally been used. However, forms of non-woven glass-fiber bags are being developed for use in either pulse-jet or reverse-air units. Other fabrics which can be used are: Teflon, which is expensive on a first cost basis but may prove lower cost on an annualized basis considering bag life; Nomex, which is subject to failure from hydrolysis if used in the wrong combination of temperature, moisture, and sulfur oxides; and homoplymer acrylics, which can be used only if the flue gas temperature is below about 280°F.*

At least two cost curves should be considered: cost vs. bag life and cost vs. A/C ratio. Bag cost is a major baghouse operating expense. The longer the bags last, the less costly is the operation. There is a point of diminishing return, however, at which the reduction in operating cost gained by another year's bag life is minimal. Depending on assumptions, that point may be about 4 or 5 years. For a given fabric the pressure drop generally increases as A/C ratio increases (and so does dust penetration). There is a point at which the increased pumping costs are greater than the reduced capital and bag costs of a smaller house predicated on higher A/C ratio. The minimum cost occurs, again depending on assumptions, at between about 4 and 8 A/C ratio. Both the above points are discussed by McKenna (4), but more recent information will be forthcoming (6).

For smaller industrial boilers, ESP's are probably more costly than baghouses. Some precipitator companies have refused to bid on a job combining small boiler size, low sulfur coal, and varying fuel supply.

*°F. = 5/9 (°F.-32)°C.

MUNICIPAL INCINERATORS

Municipal incinerators present a challenging market for particulate control. Fuel is not particularly uniform (including such things as dynamite, refrigerators, and old motorcycles) and operator attention to combustion may be minimal. With a few exceptions ESP's have not performed well. The one full scale baghouse in the U.S. known to this writer gave good performance (0.02 grains/s.c.f.) but apparently suffered from faulty construction design. Baghouse problems may have centered on inadequate treatment of moisture problems. A baghouse in Switzerland is reported to be operating with no particular problems. (7)

In the U.S., the EPA has sponsored pilot scale work at an unprepared feed, trash-to-energy incinerator. (8) Performance and projected economics favor a baghouse over an ESP at this location, although this is one of the few places where an ESP seems to be working satisfactorily.

BAGHOUSE OPERATION

An excellent discussion of start-up procedures for a boiler baghouse is given by Perkins. (9) He stresses such things as having a bypass for the baghouse; insulation, heating, and sealing to prevent condensation; inlet opacity monitors to aid the boiler operator (since there is usually no visible emission to let the operator know if he is firing the boiler improperly); and thorough inspection and checkout of the unit. In general, incomplete combustion should be avoided, and any condition that produces a sticky particulate may be cause for bypassing. The fabric should be protected by having a layer of normal fly ash on it at all times. Another discussion of utility boiler baghouse operation is given by Spagnola. (10) He deals with some of the operational problems encountered at Sunbury such as sticking dampers, blinded bags, and detecting failed bags by use of an opacity meter. Applewhite (11) reports on nine operating baghouses and cites high pressure as the most prevalent cause of maintenance. Other maintenance items mentioned are bags, ash handling, fan wear, dampers, material buildup, and corrosion damage.

CURRENT R&D

Designs of fabric filter systems depend to a large degree on experience. Because of the formerly fragmented nature of the industry, R&D was a very low key item and was often

directed at solving field problems. As the industry becomes vertically integrated, more and more research is being done by individual companies; some of the research results even find their way into publications as well as into product changes. A significant amount of R&D is also sponsored by the EPA, including: assessment of full scale filter systems on a pair of stoker fired industrial boilers over a 2-year period; assessment of a full scale system on a 350 MW. utility boiler/turbine burning low sulfur coal over at least a 1-year period; assessment of combined SO_x/particulate control with a baghouse; mathematical/computer modeling of the fabric filtration process; field assessment of various sources with a mobile baghouse; laboratory research in several areas such as new fabrics, fiber effects, cake studies, and high velocity filtration; assessment of baghouse performance on a municipal incinerator; and research in electrostatic effects in fabric filtration. Results of some of the work are reported in References 12 through 20.

The purpose of the research is to show what baghouses are presently capable of doing, understand how they do it and prepare the way for future improvements.

SUMMARY

Baghouses are now being used to control particulate emissions from utility and industrial boilers. A variety of fabrics, cleaning methods, and air-to-cloth ratios is being used, with the utilities tending to use woven glass bags, reverse-air cleaning (sometimes with shake-assist), and A/C ratios between 2 and 3. Industrial boiler users in some cases, may use pulse-jet or modified reverse-air cleaning, Teflon, needled glass, Nomex, acrylic, or other fabrics, and A/C ratios up to about 9.

Performance testing shows baghouses to be capable of very low particulate emissions (0.0035 lb./10^6 B.t.u. input), very high reliability (nearly 100%), and cost competitiveness with ESP's at high required efficiencies, low sulfur content coal, and/or small boiler size. Proper operation and maintenance are required, as with any high efficiency system.

R&D efforts are directed toward assessment and documentation of full scale baghouse operation, better understanding of the filtration process, and improvements in current technology.

Comparative data are given in Tables 1 through 5. Conflicts in data may be caused by different assumptions, different year bases for projected values, or by different conditions for actual values. For instance, small remote stations such as Nucla and Kramer have much higher unit costs than those of Sunbury and Harrington.

Author's note, 9/79. The utility boiler New Source Performance Standard for particulate matter has been revised to 13 ng./j. (0.03 lb./10^6 B.t.u.). An industrial boiler standard is being prepared.

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Table 1. Installation, Operation and Maintenance Costs for Sunbury Baghouse[a]

Bag Filter Installation Cost

Expenditure Description	Total Cost ($)
Western Precipitator Contract (4 baghouses)	3,201,700
Structures & Improvements	372,100
Land & Land Rights	1,500
Boiler Plant Equipment	1,190,000
Ash Removal Equipment	
Precipitator Modifications	
Accessory Electrical Equipment	72,000
Overhead	662,800
Total Construction Cost	5,500,100

Estimated Operation & Maintenance Cost (@ $12/manhour)

Cost Description	Cost ($) 1973	1974	1975
Collapse Fan Power Consumption	18,600	18,600	18,600
Air Compressor Power Consumption	3,000	3,000	3,000
Instrument Department Labor	950	950	1,800
Mechanical Maintenance Labor	2,130	5,840	15,678
Electrical Maintenance Labor	7,410	3,800	6,000
Construction Department Labor	3,950	2,350	2,000
Complete Bag Replacement			
Material ($48,000/baghouse)		48,000	96,000
Labor ($11,000/baghouse)		11,000	22,000
TOTAL COST	36,040	93,540	165,078

[a]General Notes:

Installation costs are in 1972/73 dollars
Total equivalent generating capacity ~193 MW.
Design gas volume = 888,000 a.cu. ft./min.
Design temperature range = 270-350°F.
Design air-to-cloth ratio = 1.9 ft./min.
Bags were replaced in 3 of the 4 baghouses as a precaution after about 2 years.
Bags in the 4th baghouse were not replaced until some signs of ring attachment failure appeared on several of the bags. Bag endurance at that time was about 4-1/2 years.

From Reference 1

Table 2. Baghouse Equipment and Installation Cost[a] at Nucla

(Field Cost Includes Material, Labor, Field Supervision, Field Overhead, and Constructor's Fee)

Component		Field Cost	Percent
Earthwork		$ 39,000	2
Concrete - foundation		75,000	4
Structural - stairways, handrails		48,000	3
Process Equipment			
Baghouse (material only)	$631,000		
Ductwork (material only)	113,000		
Labor and Other Equipment	347,000		
Total Process Equipment		$1,091,000	63
Piping - drainage and air		56,000	3
Electrical		200,000	12
Painting		50,000	3
Instrumentation		50,000	3
Insulation		130,000	7
TOTAL		$1,739,000	

[a]Costs are in 1973/74 dollars
Total equivalent generating capacity = 38 MW.
Design gas volume = 258,720 a. cu. ft./min.
Design temperature ~275°F.
Design air-to-cloth ratio = 2.8 ft./min.
Bag life estimated at ~4 to 6 years

From Reference 3

Table 3. 1976 Operating Cost Estimate[a] at Nucla

Component	$/Year	Percent	mills/kW.h.
Direct Costs			
Maintenance Labor	2,500	0.9	0.01
Maintenance Material	8,500	3.0	0.05
Utilities	31,000	10.8	0.16
Ash Handling	11,000	3.8	0.06
Subtotal, Directs	$53,000	18.5	0.28
Indirect Costs			
Depreciation - 4.9%	127,000	44.3	0.68
Interest - 3.4%	81,000	28.2	0.43
Insurance - 0.1%	3,000	1.0	0.02
Taxes	23,000	8.0	0.12
Subtotal, Indirects	$234,000	81.5	1.25
TOTAL	$287,000	100.0	1.53

[a]Costs are those expected for 1976 based on 55% capacity factor or 188 million kW.h./yr.

From Reference 3.

Table 4. Estimated Costs of Baghouses at Harrington and Kramer Stations

Harrington	
Approximate total cost	= $16,000,000 (1977)
Generating Capacity	= 356 MW.
Gas volume	= 1,650,000 @ 313°F.
Design air-to-cloth ratio	= 3.2 ft./min.
Fuel: Wyoming coal-subbituminous, 4.8% ash, 0.3% sulfur	
Kramer[a]	
Approximate total cost	= $12,000,000 (1977)
Generating capacity (total for 3 units)	= 112.5 MW.
Gas volume (total through 4 baghouses)	= 558,000 a.cu. ft./min. @ 365°F.
Design air-to-cloth ratio	= 1.7 ft./min.
Fuel: Wyoming coal-subbituminous, 3.7% ash, 0.7% sulfur	

[a]From Beaton, R. J. Kramer Station Bag Filter Numbers 1, 2, 3 and 4 Installation Design Specifications and Operating Experience to Date. Proceedings, 2nd International Fabric Alternatives Forum. American Air Filter Company, Louisville, Ky., 1977

Table 5a. Costs of Particulate Control Alternatives

Regulation Level, ng./j.	Coal Sulfur %	Coal Ash %	Boiler capacity, MW.e.	Particulate Control Alternative: Fabric Filters[a] Capital cost, $/kW.	Fabric Filters Annual Cost, mills/kW.h. O&M	Fabric Filters Annual Cost, mills/kW.h. Fixed	Electrostatic Precipitators Capital cost, $/kW.	Electrostatic Precipitators Annual Cost, mills/kW.h. O&M	Electrostatic Precipitators Annual Cost, mills/kW.h. Fixed	Venturi Scrubbers[b] Capital cost, $/kW.	Venturi Scrubbers Annual Cost, mills/kW.h. O&M	Venturi Scrubbers Annual Cost, mills/kW.h. Fixed
3.0	0.6	8.0	25				182.20	3.27	5.44			
			100				98.22	1.72	2.93			
			200	69.47	0.37	1.93						
			500	58.45	0.34	1.62	80.71	1.36	2.41			
			1000	53.56	0.33	1.48	73.37	1.24	2.19			
	3.5	14.0	25				91.00	1.84	2.72			
			100				57.32	0.98	1.71			
			200	59.89	0.32	1.65						
			500	51.83	0.29	1.43	31.82	0.54	0.95			
			1000	46.73	0.28	1.30	28.96	0.48	0.87			
6.0	0.6	8.0	25				171.40	3.07	5.12	177.08	1.41	6.98
			100				90.67	1.58	2.71	129.47	1.29	5.10
			500				68.45	1.17	2.04	72.84	0.79	2.98
			1000				65.13	1.10	1.94	58.72	0.59	2.27
	3.5	14.0	25				89.80	1.81	2.68	178.48	1.45	7.15
			100				53.16	0.91	1.59	128.10	1.30	5.15
			500				28.21	0.47	0.84	72.63	0.80	3.03
			1000				24.76	0.41	0.74	68.65	0.78	2.87
3.0	0.6	8.0	25				134.60	2.49	4.02	111.64	1.38	4.40
			100				76.06	1.32	2.27	101.04	1.25	3.98
			500				52.53	0.89	1.57	58.93	0.76	2.41
			1000				50.15	0.84	1.50	46.07	0.56	1.78
	3.5	14.0	25				91.80	1.82	2.74	112.52	1.42	4.51
			100				51.11	0.87	1.53	99.97	1.26	4.02
			500				26.85	0.45	0.80	58.67	0.77	2.45
			1000				23.61	0.39	0.71	57.21	0.75	2.39

[a] Level examined was 13.4 ng./j. which is best control vendors will guarantee.
[b] Costs are for venturis as an integral part of a flue gas desulfurization system.
From Reference 21

Table 5b. Particulate Emission Control Device Design Parameters

Control System	Design Parameter	Coal Type: Eastern, 3.5% S; Regulation level, ng./j. (lb./10^6 B.t.u.) 43 (0.1)	22 (0.05)	13 (0.03)	Western, 0.8% S; Regulation level, ng./j. (lb./10^6 B.t.u.) 43 (0.1)	22 (0.05)	13 (0.03)
ESP	Type, hot or cold	Cold	Cold	Cold	Hot	Hot	Hot
	SCA, sq.m/cu.m./sec. (sq.ft./1000 a.cu.ft./min)	47 (240)	59 (300)	71 (360)	79 (400)	108 (550)	128 (650)
	Temperature, °C (°F)	154 (310)	154 (310)	154 (310)	371 (700)	371 (700)	371 (700)
Fabric Filter	Air-to-cloth ratio cu.m./sec./sq.m. (a.cu.ft./min/sq.ft.)			0.01:1 (2:1)			0.01:1 (2:1)
Venturi Scrubber	L/G ratio, l./cu.m. (gal./100 a.cu.ft./min.)	2 (15)	2 (15)		2 (15)	2 (15)	
	Gas velocity, m./sec. (ft./sec.)	38 (125)	38 (125)		38 (125)	38 (125)	
	Pressure Drop, mm. H_2O (in. H_2O)	203 (8)	762 (30)		203 (8)	762 (30)	

From Reference 21

Table 5c. Model Plant Parameters and Assumptions Used in the Particulate Control Analysis

Model Plant Parameters	Characteristics and Assumptions
Plant capacities, MW.	25, 100, 200, 500, and 1000 (single boilers)
Plant status	New
Coal characteristics	(See Table 5d)
Particulate control requirements	(1) The existing NSPS of 43 ng particulate/joule heat input (0.1 lb./10^6 B.T.u.) (2) 22 ng. particulate/joule heat input (0.05 lb./10^6 B.t.u.) (3) 13 ng. particulate/joule heat input (0.03 lb./10^6 B.t.u.)
Location	Midwest location - East North Central Region
Boiler data	
Capacity factor	Assume 0.65 for all plants
Heat rates, flue gas flow rates, and remaining life	

Capacity, MW.	10^3 Heat rate[a], joules/kW.h.	(B.t.u./kW.h.)	Flue gas[a] flow rate, cu.m./sec./MW.	(a.cu.ft./min./Mw.)	Remaining life, yr.
25	10,540	(10,000)	1.65	(3,500)	35
100	10,013	(9,500)	1.58	(3,350)	35
200	9,700	(9,200)	1.50	(3,175)	35
500	9,490	(9,000)	1.45	(3,080	35
1,000	9,170	(8,700)	1.42	(3,000)	35

Flue gas temperature	Assumed 155°C. (310°F.) for all plants

[a]Detailed Cost Estimates for Advanced Effluent Desulfurization Processes, prepared for Control Systems Laboratory, Office of Research and Development, U. S. Environmental Protection Agency, under Interagency Agreement EPA (AG-134(d) Part A, by G. C. McGlamery, et al., Tennessee Valley Authority, pp. 60,66, May 1974.

From Reference 21

Table 5d. Coal Analyses Used in Calculating Particulate Control Costs

Coal Type	% Sulfur, by wt.	Ash, % by wt.	10^3 Heating value, joules/kg.	(B.t.u./lb.)
Eastern bituminous	3.5	14	5,737	(12,000)
Western subbituminous	0.8	8	4,781	(10,000)

From Reference 21